

Resonance production in heavy-ion collisions at STAR

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Abstract. Hadronic resonances are sensitive to the properties of a hot and dense medium created in a heavy ion collisions. During the hadronic phase, after hadronization of quark and gluons into hadrons, resonances are useful to determine the lifetime between chemical and thermal freeze-out, under the assumption that the re-scattering of the decay particles and the probability of regeneration of resonances from hadrons depends on the system properties and the resonance lifetime. The system size and energy dependence of resonance spectra and yields will be shown and discussed in the context of the lifetime and size of the hadronic phase. Elliptic flow measurement will extend the sensitivity of resonance yields to the partonic state through additional information on constituent quark scaling. We also explore a possible new technique to extract signals from the early, potentially chirally symmetric, stage through the selection of resonances from jets.

1. Introduction

Due to the short lifetime of resonances (few fm/c), interactions with the partonic and hadronic medium created in a heavy ion reaction, can modify their properties. Depending on the medium conditions; energy density, temperature and the degrees of freedom, various modifications to resonance properties, such as mass, width (lifetime), yields and spectra, are expected. The so-called bulk matter of low momentum resonances, i.e. resonances with a transverse momentum of $p_T < 2$ GeV/c, are dominated by the extended dense hadronic medium due to an enhanced resonance regeneration probability. Furthermore interactions of resonance decay hadrons with the hadronic medium are present, which leads to a reduction of the resonance yield. The reconstructed resonance yields, obtained through invariant mass reconstruction based on hadronic decays, are sensitive to the lifetime, density and temperature of the hadronic medium and to the decay lifetimes of the resonances and their regeneration cross sections. The measured ratio of the resonance to non-resonance yields [2] at $\sqrt{s_{NN}} = 200$ GeV in Au+Au collisions can be described with a microscopic transport model (UrQMD) which assumes a duration between chemical and kinetic freeze-out of $\Delta\tau = 10 \pm 3$ fm/c [6]. Alternatively, suppression of the $\Lambda(1520)$ and $K(892)$ yields combined with a thermal model with an additional re-scattering phase [8, 9, 10, 11],

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suggests a hadronic lifetime of $\Delta\tau > 4$ fm/c [2]. Together with the pion HBT lifetime measurement ($\Delta\tau = 5 - 12$ fm/c) [1], which determines the time from the beginning of the collision to kinetic freeze-out, a partonic lifetime can be extracted under the assumption that the chemical freeze-out occurs at hadronization [2]. The further investigation of the lifetime and medium size dependencies of the hadronic phase on the hadronic resonances is presented in Section 2 and 3 using smaller system size (Cu+Cu collisions) and a lower Au+Au collision energy ($\sqrt{s_{NN}} = 62$ GeV).

Another observable which is sensitive to the degrees of freedom in the initial partonic phase, but which might also exhibit sensitivity to contributions from regenerated resonances in the hadronic phase, is the elliptic flow. The latter is the momentum anisotropy of emitted particles due to the spatial azimuthal asymmetry of the initial state under the assumption of maximum partonic interactions. The so-called 'constituent quark scaling' of the elliptic flow for resonances will increase if a resonance is re-combined from hadrons rather than from quarks [3]. Results will be shown in Section 4.

In order to study the partonic and early hadronic medium with resonances where chiral symmetry is possibly restored, the resonances need to be unaffected by the late hadronic medium where regeneration of resonances dilutes the signatures. Even the reconstruction of leptonic decays might be affected by the signal from the hadronically regenerated resonances. Since we know from UrQMD calculations that the regeneration is predominant in the low momentum region ($p_T < 2$ GeV/c) [6], the study of chiral symmetry restoration from leptonic decays might be only suitable in the high momentum region of $p_T > 2$ GeV/c. The same argument is valid for the hadronic decays. High momentum resonances are produced early in the reaction and less affected by the re-scattering and regeneration in the hadronic phase because the system moves with a much smaller collective velocity and thus the high momentum particles can escape, in particular if the hard scattering which produced the resonance occurs near the surface. Thus resonances from the same side jet in a triggered di-jet event should be less suppressed since they most likely traveled through less of the bulk medium. Therefore to investigate medium modification of resonances in the medium resonances from the away side, which have the longer path length in the medium need to be selected. But their momenta should be large enough to be unaffected by re-scattering and regeneration in the subsequently produced hadronic medium. This idea requires the resonances to be formed earlier than the bulk hadrons, such that hadronic resonances can traverse the partonic medium. Formation time arguments will be discussed in a later section. The analysis is based on selection of resonances from the away-side of a di-jet using a high p_T hadron trigger to select the jet axis. Early feasibility studies will be shown in Section 5.

2. System size dependence

The lifetime of the hadronic phase depends on the system size and the expansion velocity. Elementary p+p collisions exhibit a small system size and a nearly zero lifespan of the

hadronic phase. We studied the ratios of resonances to stable particles with respect to centrality defined by the multiplicity of produced charged particles. We measured a suppression of K^*/K^- [7] and Λ^*/Λ [2] in central Au+Au compared to minimum bias p+p collisions. Due to large errors the onset of the suppression from minimum bias p+p to peripheral Au+Au collisions could not be assigned to a narrow multiplicity range. With the new K^*/K^- [4, 5] from Cu+Cu collisions we are able to better differentiate the low multiplicity region due to the smaller system size of the Cu nuclei. Fig. 1 shows the ratio of K^*/K^- versus the charged particle multiplicity for Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV. The agreement in the data shows that the suppression of resonances scales with charged particle multiplicity. Furthermore the onset of the suppression seems to be occurring at a very low multiplicity and the maximum suppression is reached already at $dN_{ch}/d\eta = 100$ and remains constant out to the most central Au+Au collision ($dN_{ch}/d\eta = 700$). This implies that the hadronic lifetime between the peripheral and central collisions remains constant. This trend is similar for the temperature separation between chemical and thermal freeze-out shown in figure 1 (left).

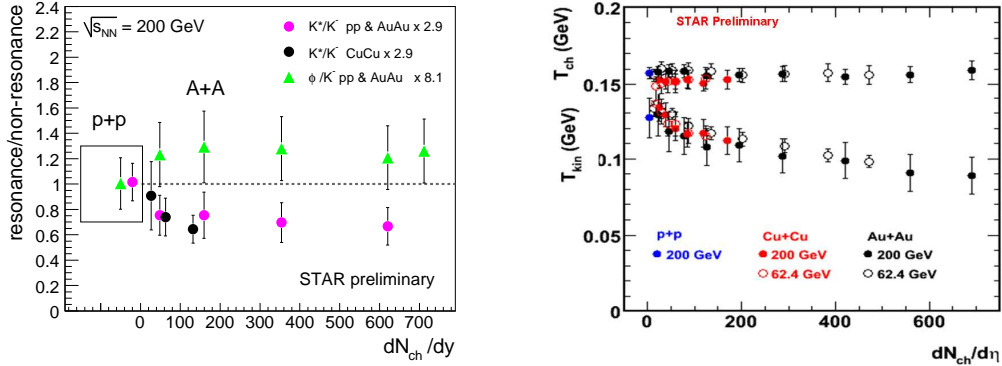


Figure 1. Left: Ratio of K^*/K^- and ϕ/K^- versus $dN_{ch}/d\eta$ of Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV. The ratios are normalized to unity in p+p collisions. The Cu+Cu data only include statistical errors. Right: Chemical and kinetic freeze-out temperatures versus $dN_{ch}/d\eta$ [5].

3. Energy dependence

Fig. 2 (left) shows the ratio of K^*/K^- and ϕ/K^- versus the charged particle multiplicity of Au+Au collisions at two different energies, $\sqrt{s_{NN}} = 200$ GeV and $\sqrt{s_{NN}} = 62$ GeV. The K^*/K^- data indicate a smaller suppression at lower energies in the most peripheral collisions. In central collisions the suppression of the K^*/K^- is the same for both collision energies. This would indicate that the hadronic lifetime or the re-scattering cross section increase, as a function of centrality, is slower in lower energy collisions. The mean transverse momentum shown in Fig. 2 (right) confirms the larger re-scattering contribution, which increases the mean transverse momentum in peripheral collisions at the higher incident energy.

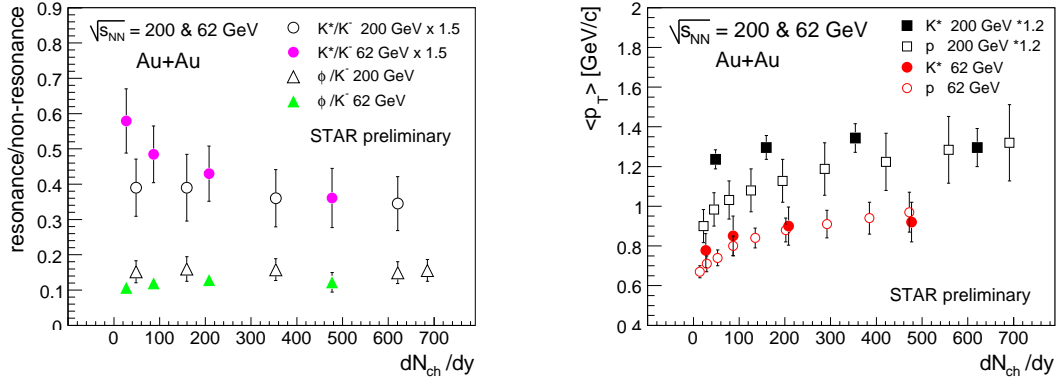


Figure 2. Left: Ratio of K^*/K^- and ϕ/K^- versus $dN_{ch}/d\eta$ of Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and $\sqrt{s_{NN}} = 62$ GeV. Right: The $\langle p_T \rangle$ versus $dN_{ch}/d\eta$ of K^* and a non-resonant particle of similar mass (proton) in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and $\sqrt{s_{NN}} = 62$ GeV.

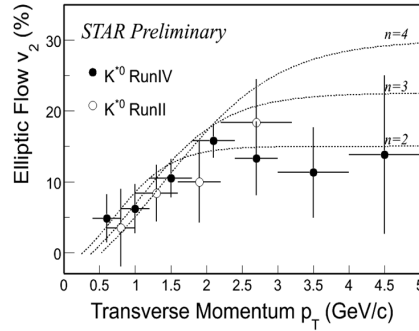


Figure 3. Elliptic flow of K^* versus the transverse momentum. The lines show the predictions for a constituent quark scaling of 2, 3 and 4. [7, 3]

4. Elliptic flow

Based on constituent quark scaling considerations, the elliptic flow of directly produced K^* from partons should scale with two (two constituent quarks), while the flow of recombined K^* , which are generated from a two meson interaction, should scale with four (four constituent quarks) [3]. According to Nonaka's calculations the elliptic flow of K^* will increase by about 15% in the transverse momentum region of 3-5 GeV/c if both contributions are mixed according to a recombination model. Presently the error in our K^* flow determination, shown in Figure 3 [7], is too large and the measurement is not sufficiently sensitive to observe a possible increase of the elliptic flow. The error will improve with the run 7 data.

5. Resonances from Jets

The isolation of resonances from an away-side jet which passes through the partonic medium might be a suitable measurement to investigate the effect of the partonic or

early hadronic medium on resonances with respect to mass shifts and width broadenings [12]. High momentum resonances from the away-side jet are identified via the angle with respect to the jet axis or leading particle (see Figure 4). A high transverse momentum resonance in the away-side jet cone is likely to be produced early, which, depending on its formation time, can interact with the early partonic medium but leaves the medium quickly enough to not exhibit any interaction with the later hadronic phase. The formation time of a resonance in the string fragmentation process depends on the momentum fraction z carried by the resonance. In addition there is a parton and resonance mass dependence which leads to shorter formation times for heavy resonances. A quantum mechanical treatment of heavy meson formation in heavy-ion collisions is shown in [15]. The authors demonstrate that the probability of high momentum heavy hadron (or resonance) formation in the partonic medium is finite. An alternate approach, based on string fragmentation [14], arrives at a similar conclusion for heavy mass, light quark objects. Quantitative studies of resonance properties such as yield, mass, width, and branching ratio as a function of resonance momentum, emission angle, jet energy, and jet tag, might therefore directly address the question of chiral symmetry restoration.

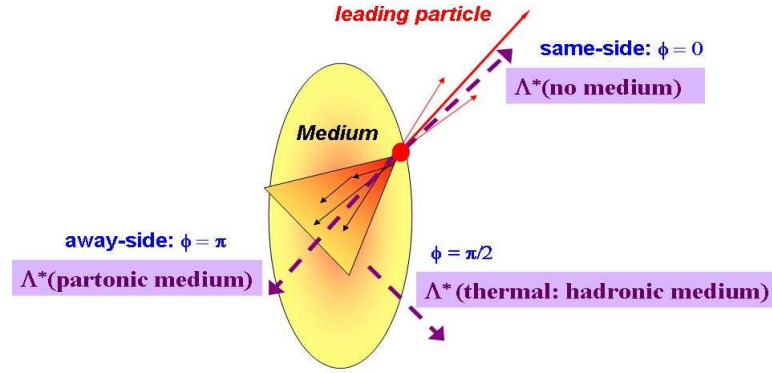


Figure 4. Sketch of jet fragmentation into resonances (Λ^* , $\phi(1020)$,...) in the medium created in a heavy-ion collision. Same-side correlations of resonances are not affected by the medium, whereas the away-side high p_T resonance might be affected by the early (chiral symmetry restored) medium. Thermal resonances, which are affected by the late hadronic medium are at $\pi/2$ with respect to the trigger particle.

A first attempt of this correlation analysis was done using the $\phi(1020)$ meson and a charged leading particle [12]. The masses and widths of the $\phi(1020)$ signals for the different angular selections are in agreement with the PDG value. Due to the low momentum of the associated $\phi(1020)$ particle most of them are from the late hadronic medium and therefore we are not sensitive to mass shifts or width broadenings. Alternatively $\phi(1020)$ are selected via invariant mass cut and correlated with a high momentum trigger hadron. Figure 5 shows the raw hadron- $\phi(1020)$ correlation after normalization and subtraction of the mixed-event background with the lowest point at zero. This preliminary result is not corrected for elliptic flow (v_2) contribution and has no systematic error estimation. However the trend of a larger resonance production

on the away-side of the $\Delta\phi$ correlation compared to the same side is present in the angle dependent mass distribution. This effect might be due to energy conservation (trigger bias), however. More statistics in the present analysis as well as production runs with the new Time of Flight upgrade detector in the future will help us to identify the resonance decay daughters out to higher momenta and therefore reduce the combinatorial background up to factor of 10.

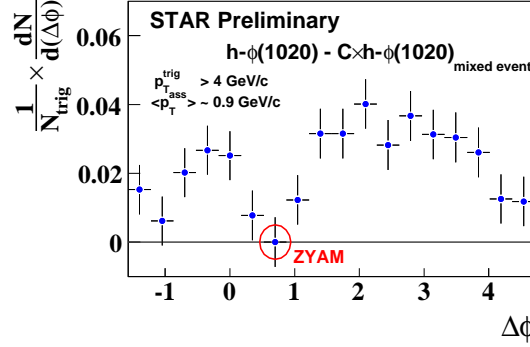


Figure 5. STAR, angular correlation of hadron- $\phi(1020)$ resonance. Hadron trigger $p_T > 4$ GeV/c and associated $\phi(1020)$ $\langle p_T \rangle \sim 0.9$ GeV/c [12].

6. Conclusion

Hadronic decays of resonances with different lifetimes are used to extract information about the time evolution and temperature of the expanding hadronic medium. Data from the smaller system (CuCu) exhibit the same dependence of the resonance suppression versus the charged particle production as measured in AuAu. The K^*/K^- ratios from Cu+Cu collisions indicate that the hadronic lifetime remains constant from 200 out to 700 produced charged particles (per rapidity unit). The $\sqrt{s_{NN}} = 62$ GeV data indicate a slower decrease of the K^*/K^- ratio and a slower increase of mean p_T versus the centrality compared to the $\sqrt{s_{NN}} = 200$ GeV data. These results can be interpreted as a slower increase of the hadronic lifetime at lower collision energies. Resonances from jets are being investigated as a tool to access early-produced resonances, which are unaffected by the hadronic medium, in order to study chiral symmetry restoration.

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